Inelastic Dipole Dark Matter at FASER

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ForwArd Search ExpeRiment (FASER)

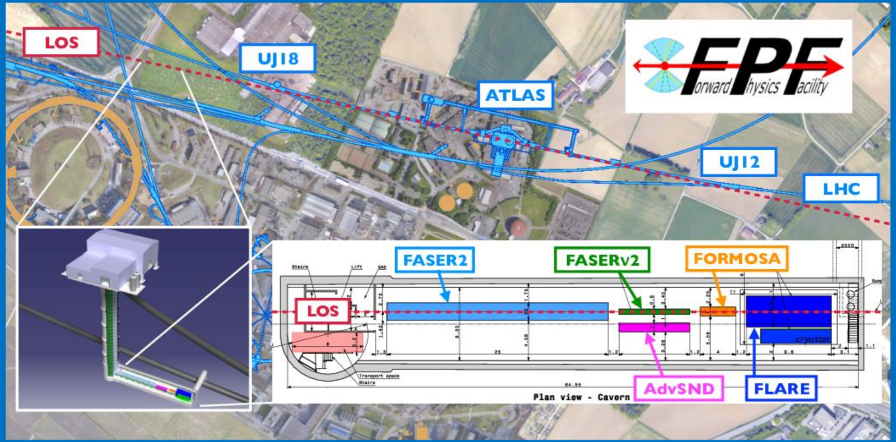
- 500m from ATLAS IP

- large flux of particles produced in the forward direction:

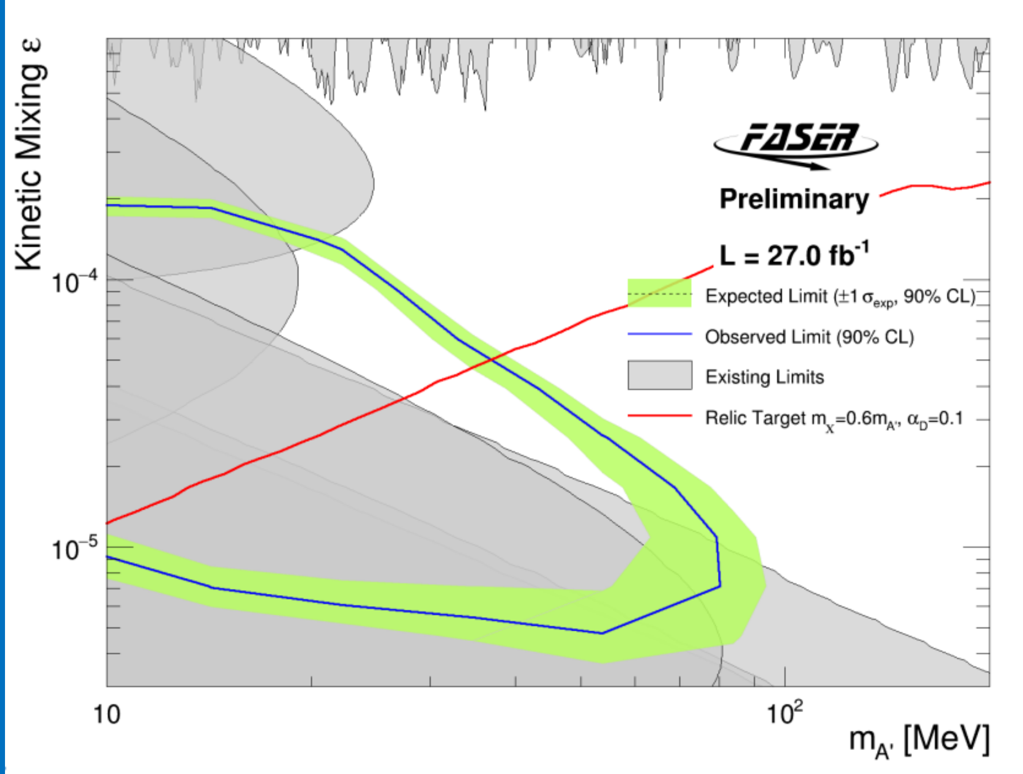
$\nu, \pi^0, K, D^0, \rho,\ J/\psi\ \ldots, A'?\ \chi?\ a?$

- Very low backgrounds: μ, ν

- Proposed upgrade, FASER2, along with the rest of the Forward Physics Facility



Recent FASER Results



Dark Photon Analysis

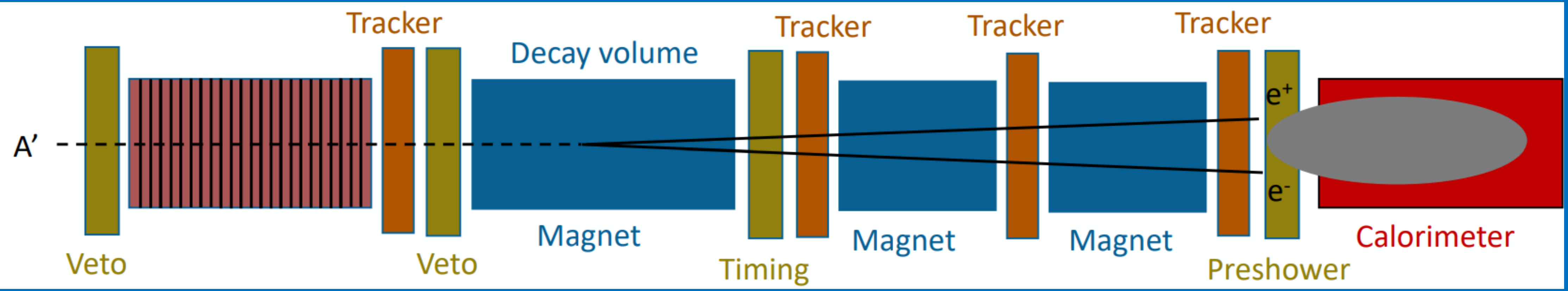
$$\pi^0, \eta, \eta' \rightarrow A'\gamma, A' \rightarrow e^+e^-$$

$$N_{bgd} \approx 10^{-3}$$

$$N_{sig} = 0$$ ☹

No signal events, resulting in exclusion.

What other models / signatures can we look for?



What models make motivated targets for FASER?

Need an LLP

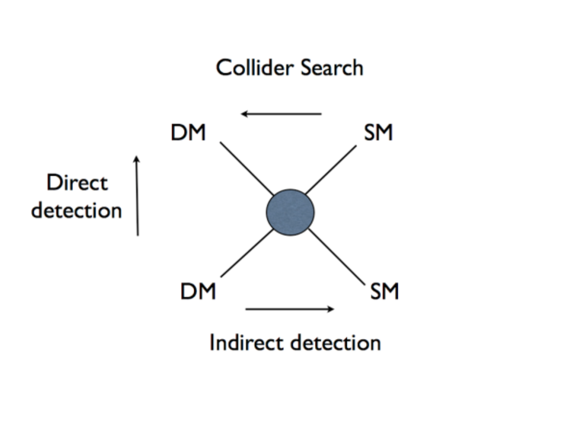
Novel SM signature

Uniquely suited for FASER (ideally)

Low Bgd

Large Boosts

Bonus: can describe DM?



Magnetic Inelastic Dipole (Dark Matter)

- We look at the minimal model

$$\mathcal{L} \supset \frac{1}{\Lambda_m} \bar{\chi}_1 \sigma^{\mu\nu} \chi_0 F_{\mu\nu} + h.c.$$

$\frac{m_1 - m_0}{m_0} \equiv \Delta$ 1508.03050

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Monophoton

2203.05090
2207.05100
2209.13469

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Exploit LHC boost

$$E_\gamma \approx 1\,\text{GeV}\, \frac{E\chi_1}{1\,\text{TeV}}\, \frac{\Delta}{0.001}$$

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Can also describe dark matter!
- Abundance through freezeout
- Direct detection evaded with sufficient Δ

~~Magnetic~~ Electric Inelastic Dipole (Dark Matter)

- We look at the minimal model

$$\mathcal{L} \supset \frac{1}{\Lambda_m} \bar{\chi}_1 \sigma^{\mu\nu} \gamma^5 \chi_0 F_{\mu\nu} + h.c.$$

LLP

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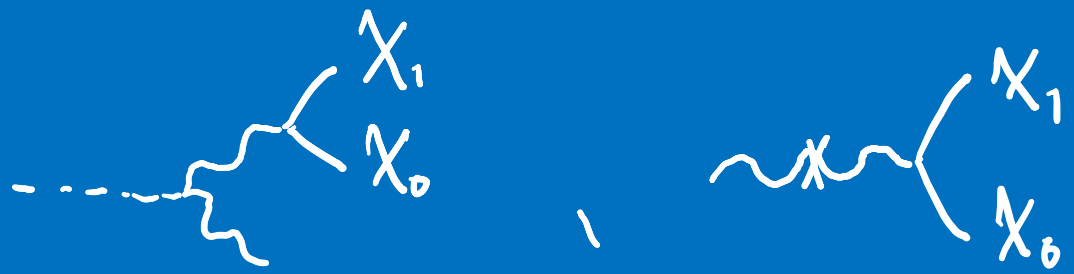
How to produce χ_1?

- Plenty of mesons produced in the forward direction during Run3 and HL-LHC

$10^{16}\pi^0,\ 10^{15}\,\eta\,,10^{12}\rho\,,10^{11}J/\psi\ldots$

Meson mass



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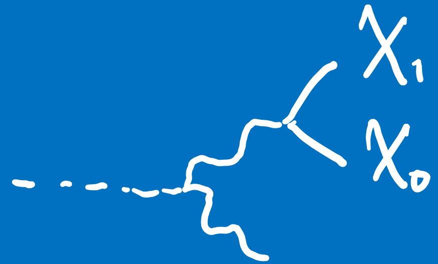

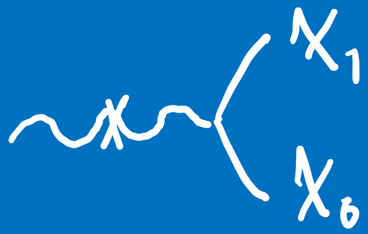

Heavier mesons have lower flux but this is compensated by the branching fraction

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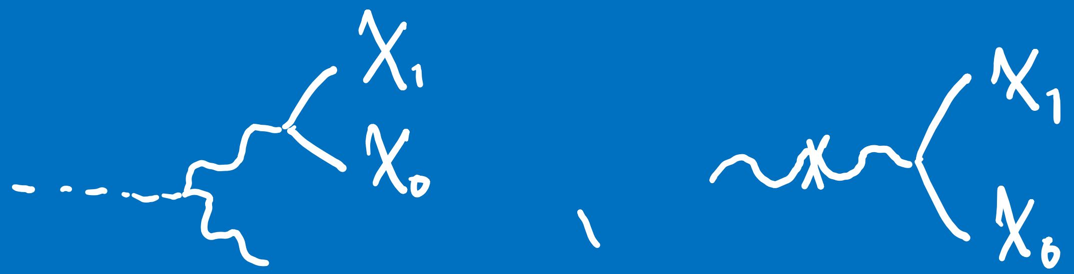

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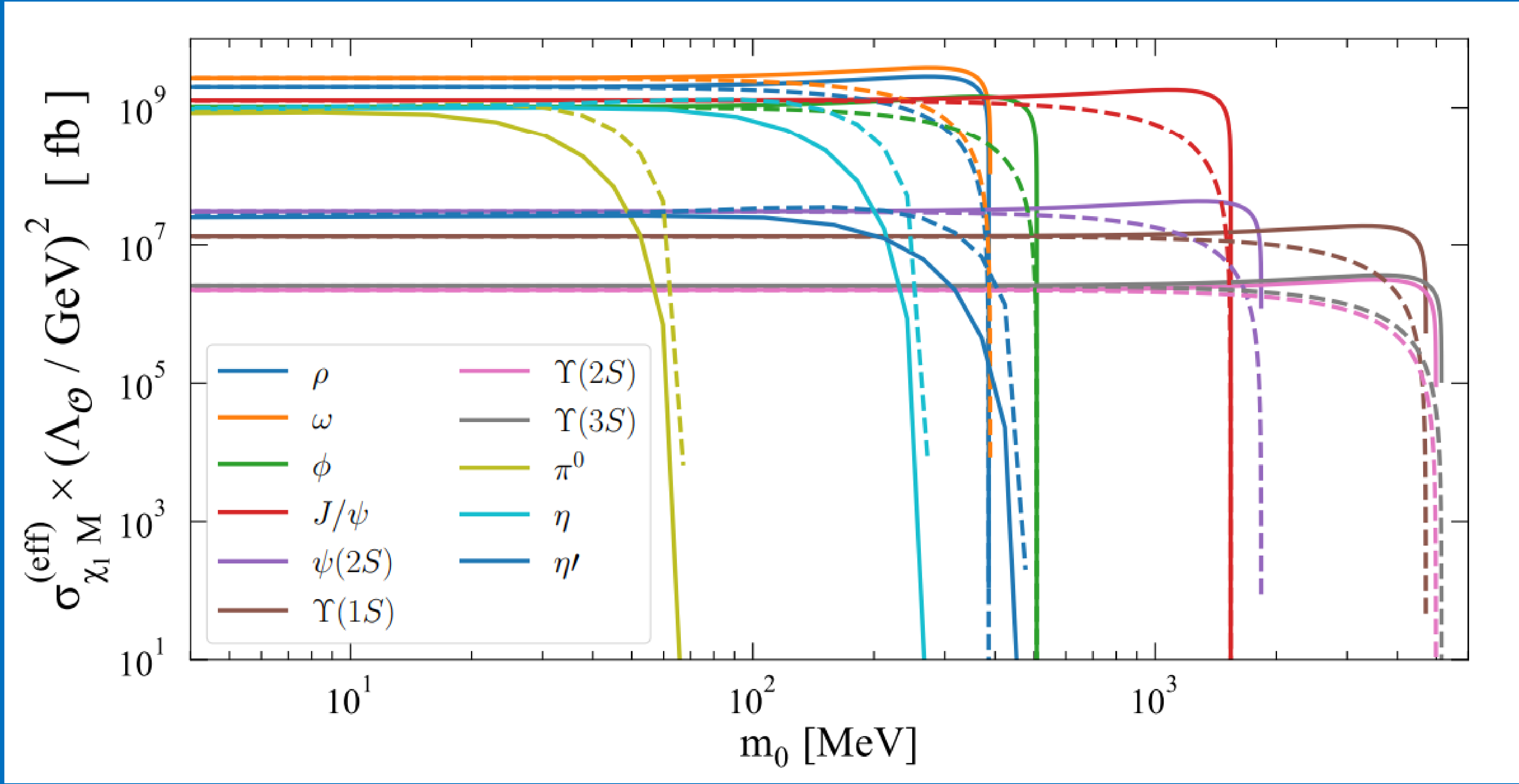
Heavier mesons impart larger p_T, so larger FASER2 will better exploit these

$$R_{\mathrm{FASER}} = 10\ cm\ ,\ R_{\mathrm{FASER2}} = 100\ cm$$

χ_1 Production

- Normalized production: $pp \to M \to \chi_0 \chi_1 (\gamma)$ in FASER for magnetic (solid) and electric (dashed)



Can reach O(1) GeV

EDM case shows p-wave suppression

What is the signal and background?

What is the signal at FASER?

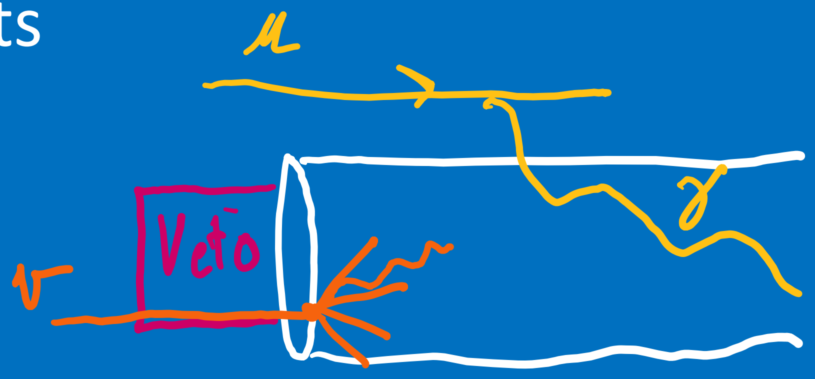
- Photon hits in the calorimeter with $E_\gamma \approx 10\ \mathrm{GeV} \times \frac{\Delta}{0.01}$
- Photon ID with pre-shower detector

Backgrounds?

μ: Either vetoed or produce O(10) MeV deposits

We take $E_\gamma > 300\ \mathrm{MeV}$

ν: Vetoed by preshower and trackers



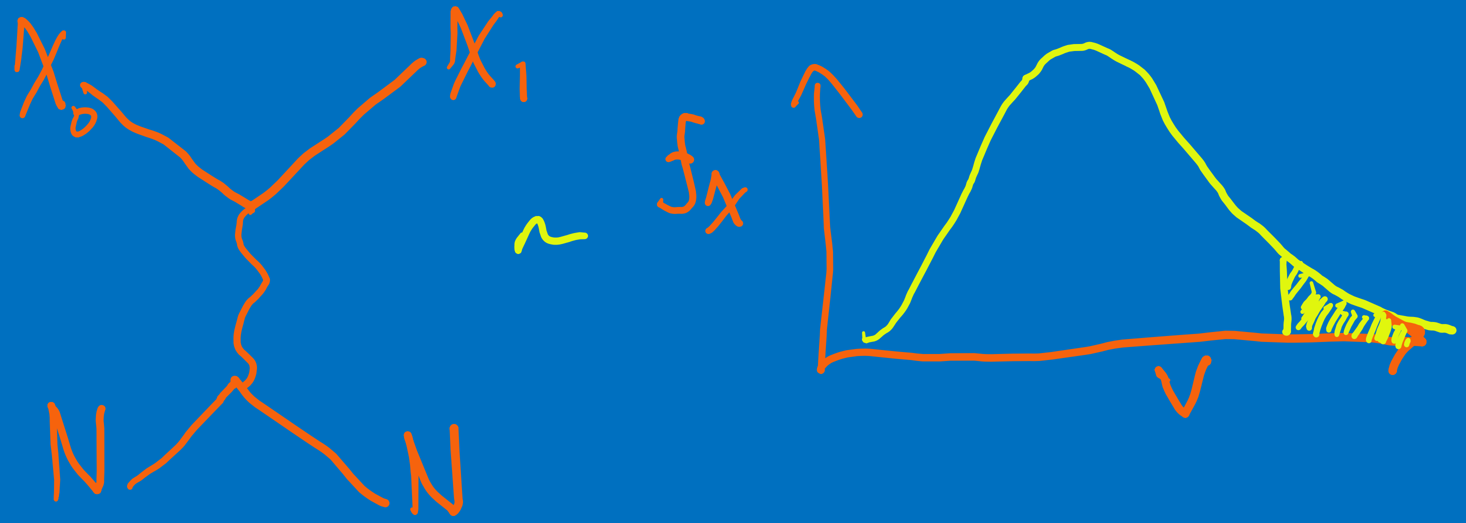
What about dark matter?

Dark Matter

- Splitting well-above direct detection reach

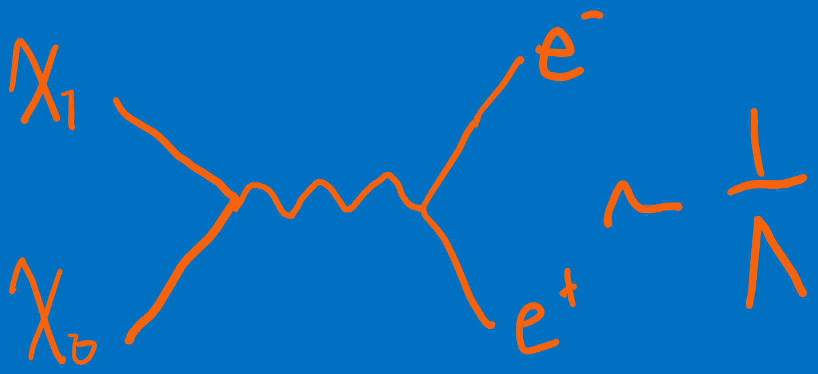
$$\frac{E_{\text{kinetic}}}{m_1 - m_0} \sim \frac{10^{-6}}{\Delta} \ll 1$$

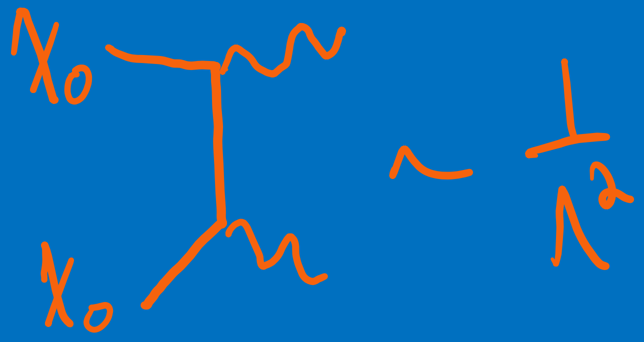
$\Delta \sim 0.01$



Dark Matter

- Freezeout process governed by (co-)annihilation processes





Less Λ suppression in s-channel but Boltzmann suppressed

t-channel no Boltzmann suppression but doubly suppressed by Λ

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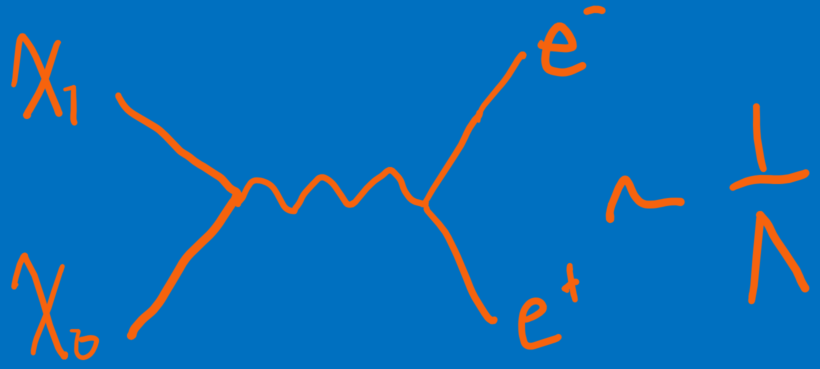

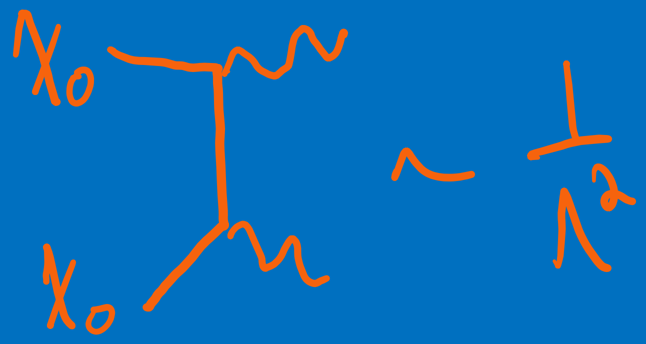

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t-channel no Boltzmann suppression but doubly suppressed by Λ

Bottom line:

-for small $\Delta \ll 1\%$: s-channel dominates, but have direct detection constraints

-for large $\Delta \sim 1$: t-channel dominates - need large couplings for F.O. that are excluded

-for $\Delta \sim 1\%$: unprobed masses and couplings that give right relic abundance

Results

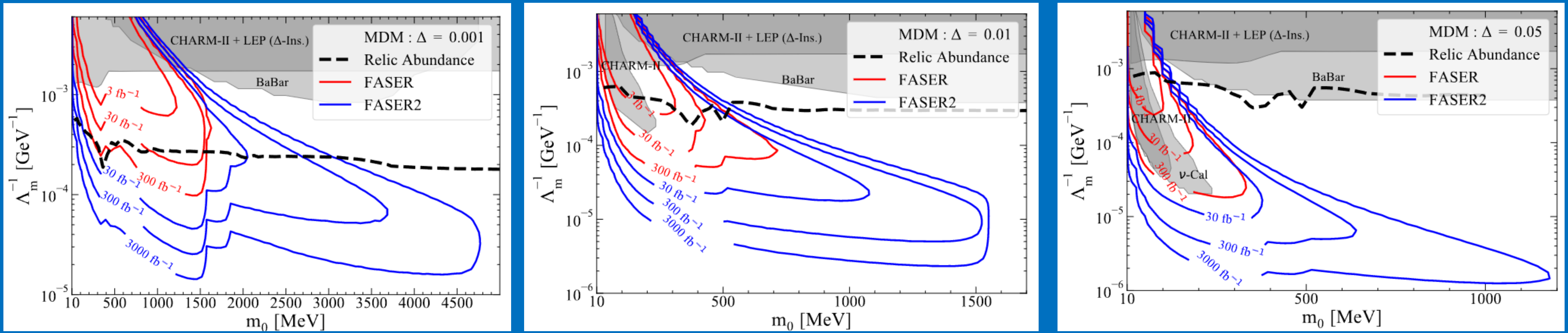
Detection
-Production
-Background
-Signal

Dark Matter
-D.D.
-F.O.

Results
-$\Delta = \{0.001\,, 0.01\,, 0.05\}$
-Λ^{-1}, m_0
-MDM (EDM)

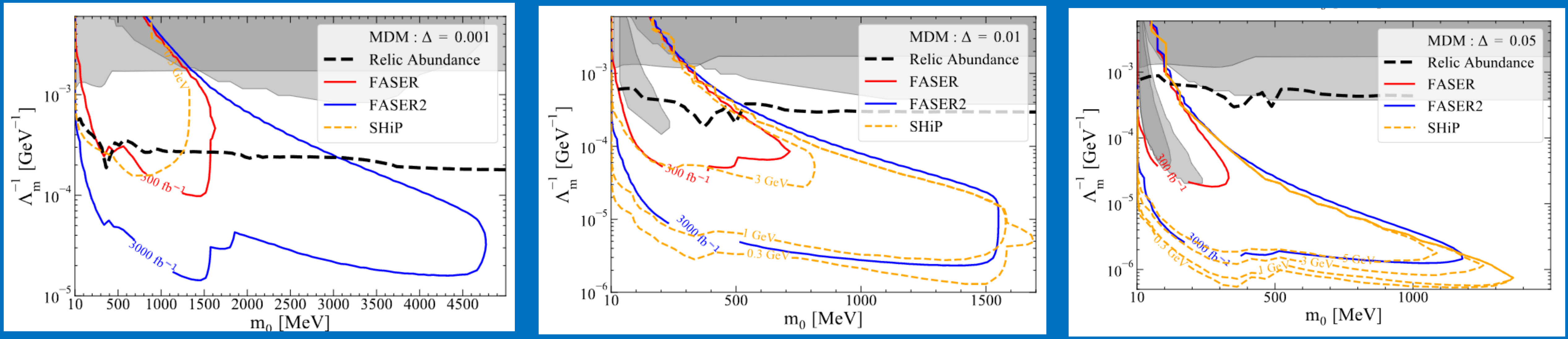
Results

MDM



Increasing Δ

SHiP projections



Increasing Δ

Summary

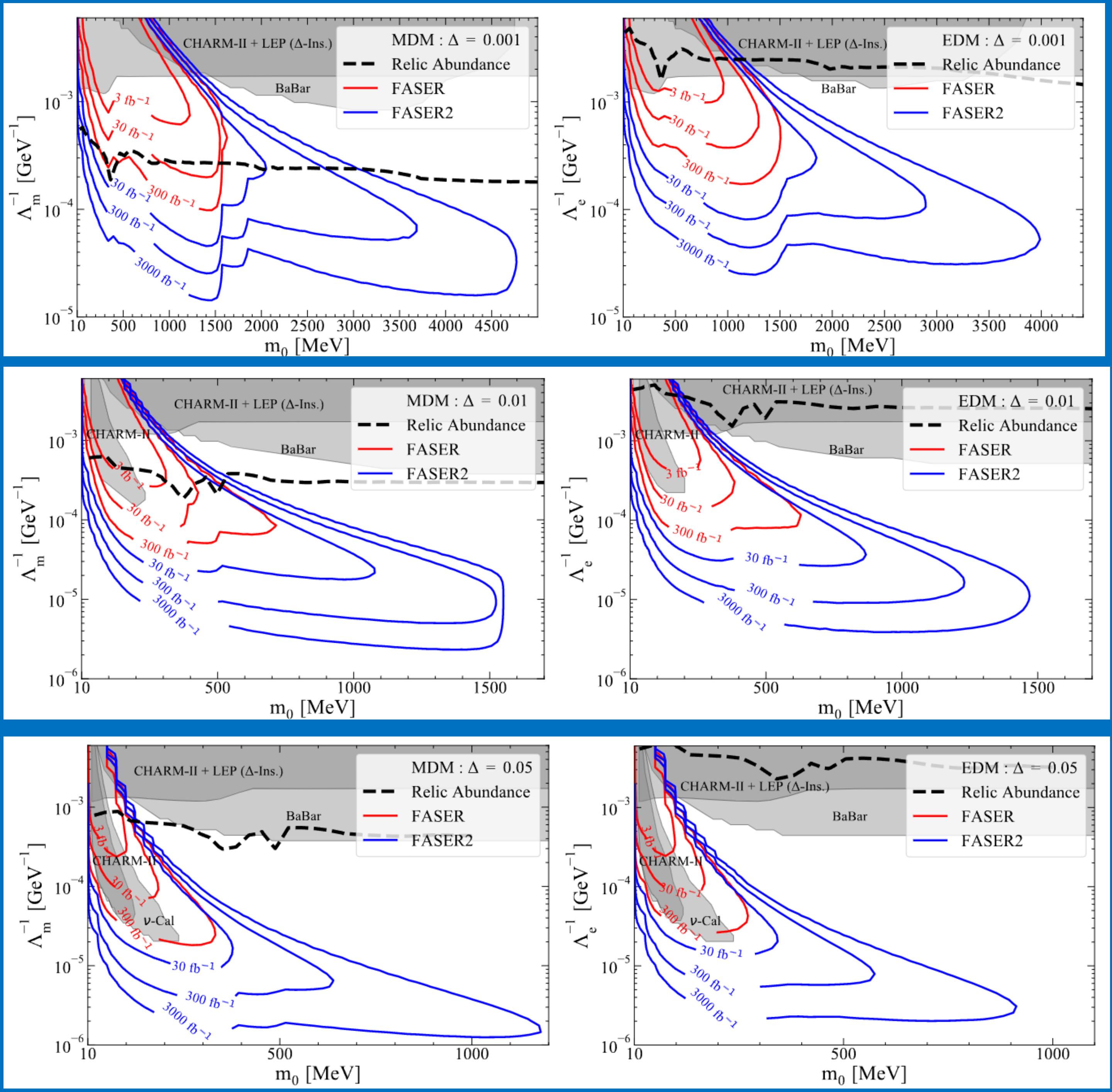
$\Delta = \{0.001, 0.01, 0.05\}$

- FASER can search for $\gamma' s$ from inelastic dipole DM decay
- Best suited to explore signals that would be too soft at other experiments

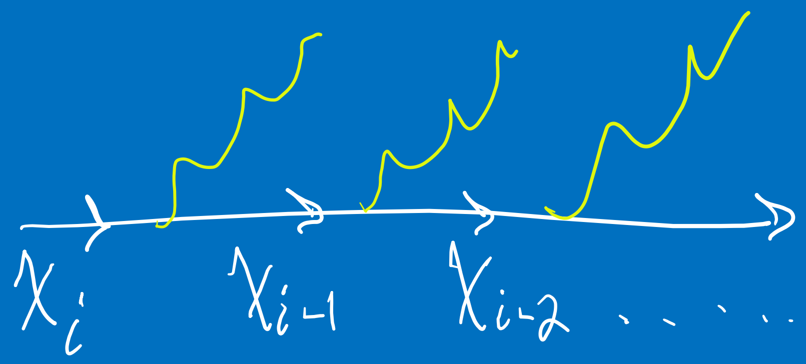
If DM is thermally produced and interacts via MIDM

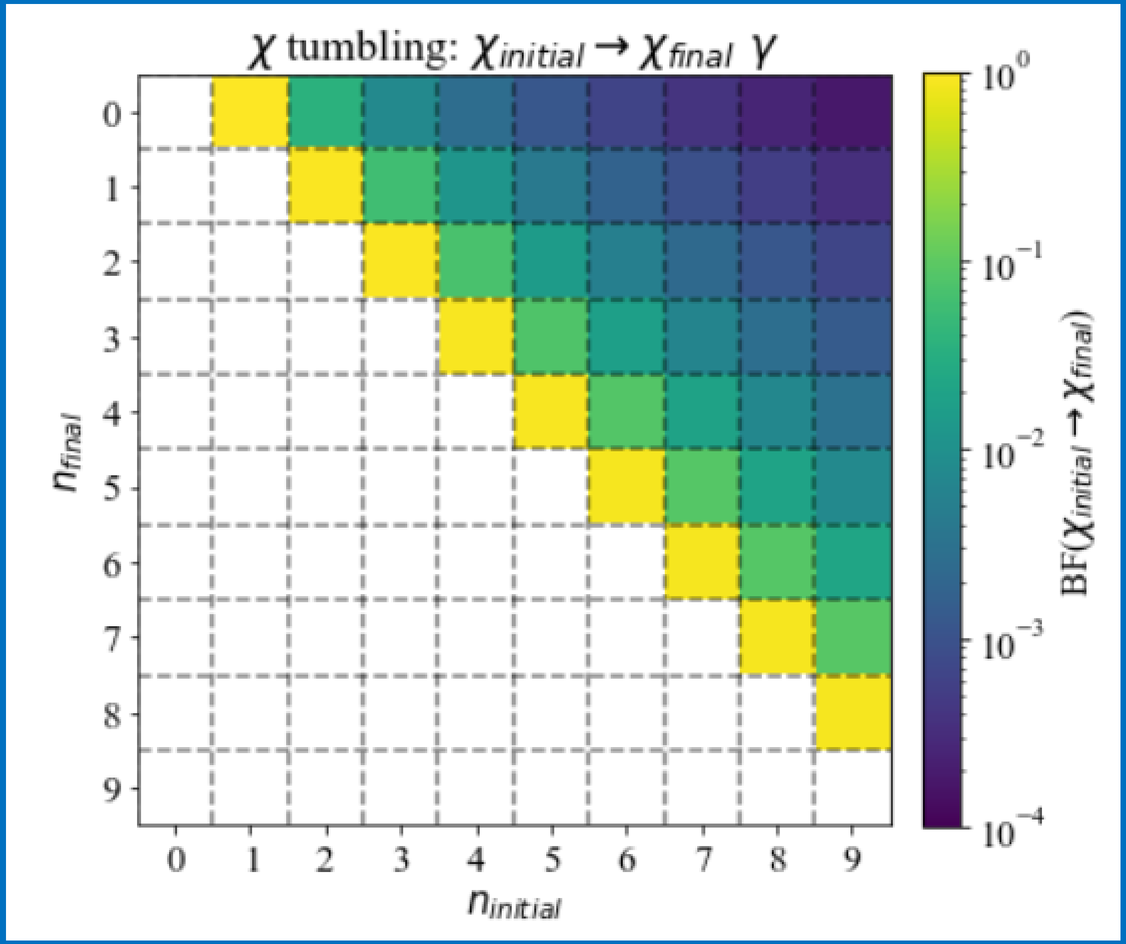
→ then only $\Delta < 0.05$ is unexcluded for GeV masses

→ FASER can probe



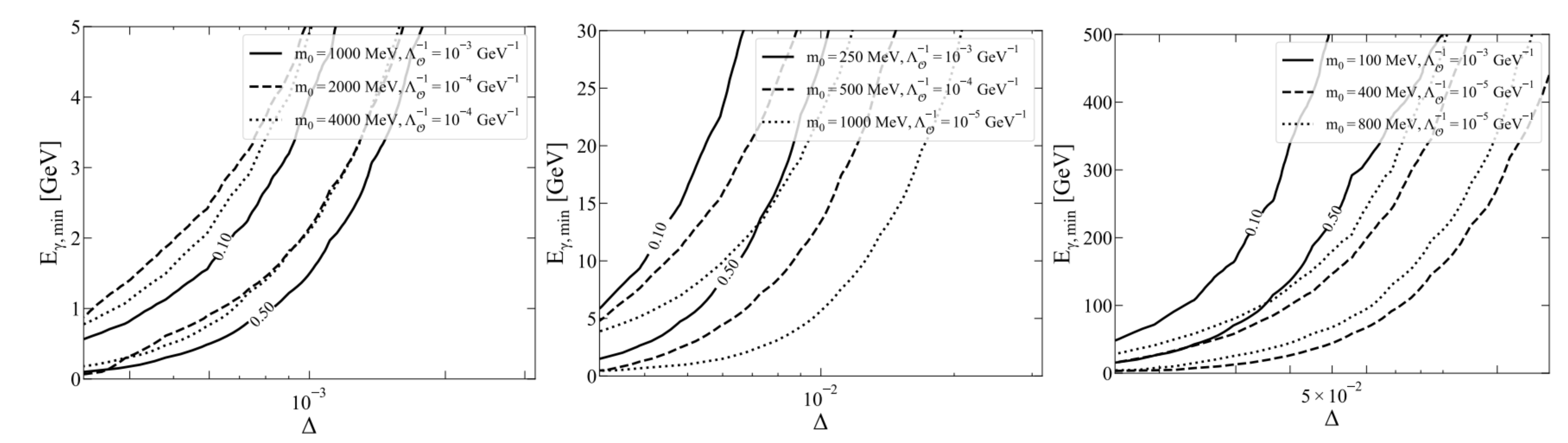
Future work: add more states and tumble down the tower…



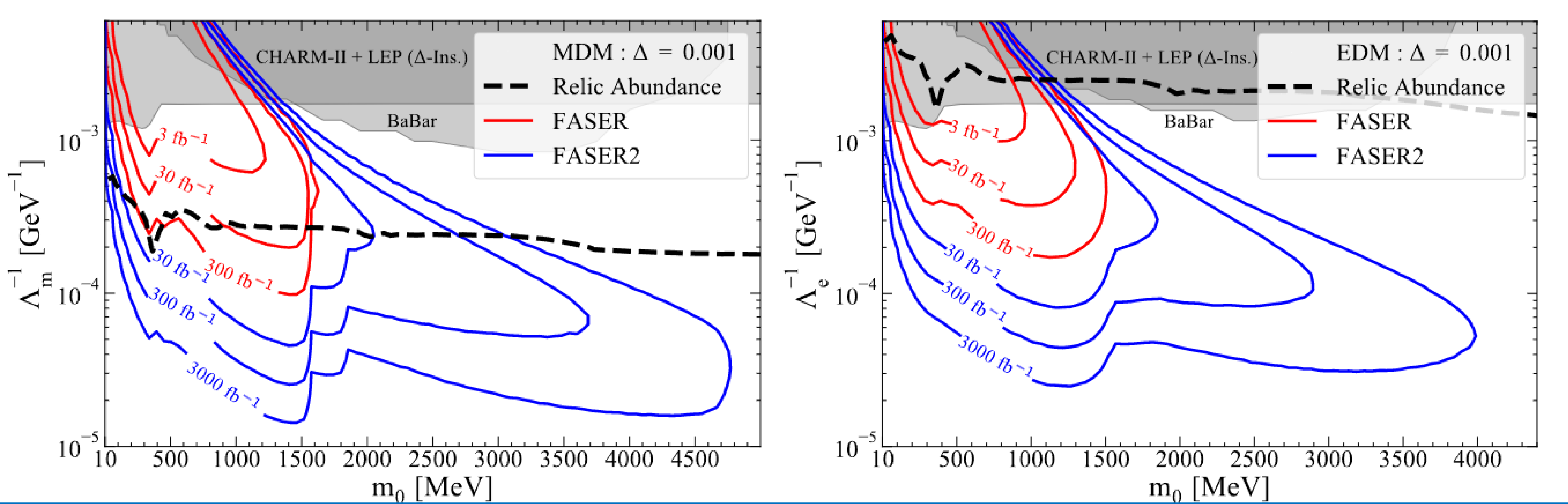


Thank you!

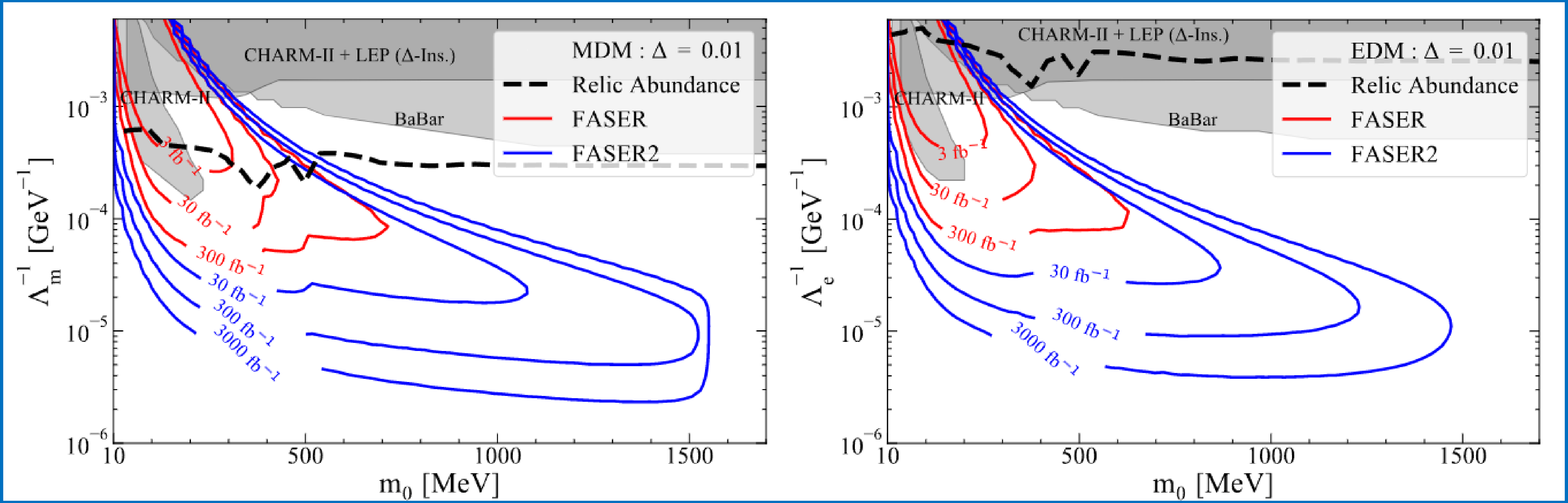
Results

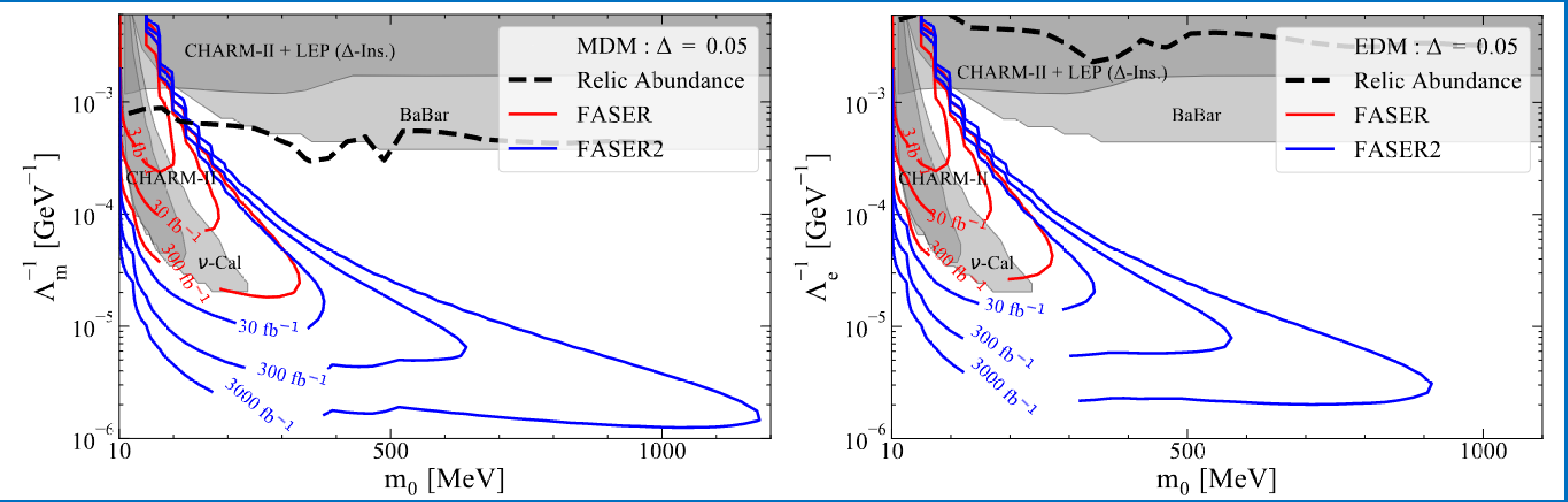


$m_0 = 1000$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-3}$ GeV^{-1}
$m_0 = 2000$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-4}$ GeV^{-1}
$m_0 = 4000$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-4}$ GeV^{-1}
$E_{\gamma,\min}$ [GeV]
Δ
10^{-3}
0.10
0.50
$m_0 = 250$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-3}$ GeV^{-1}
$m_0 = 500$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-4}$ GeV^{-1}
$m_0 = 1000$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-5}$ GeV^{-1}
10^{-2}
$m_0 = 100$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-3}$ GeV^{-1}
$m_0 = 400$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-5}$ GeV^{-1}
$m_0 = 800$ MeV, $\Lambda_{\mathcal{O}}^{-1} = 10^{-5}$ GeV^{-1}
5×10^{-2}

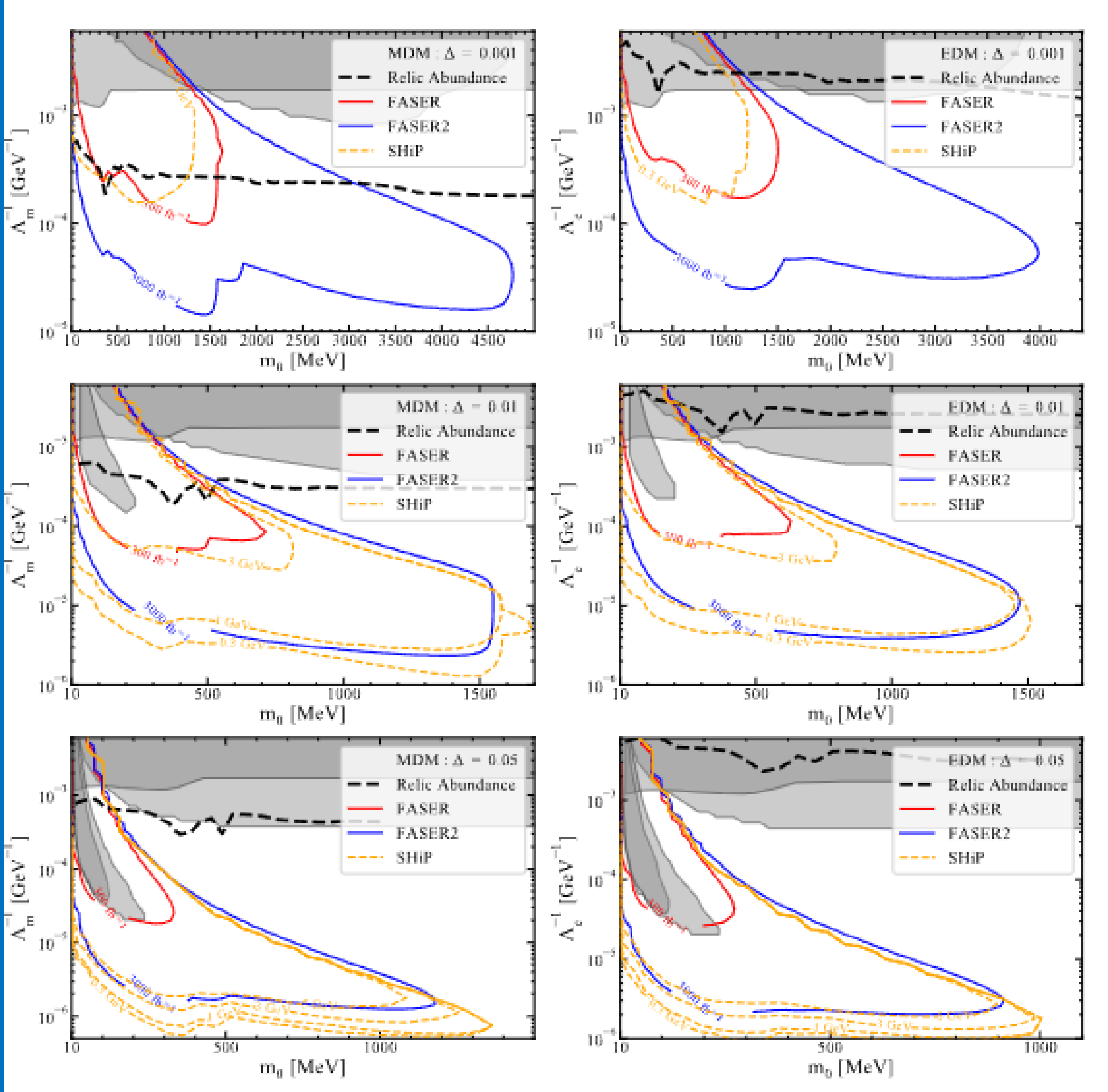


CHARM-II + LEP (Δ-Ins.)
MDM : Δ = 0.001
Relic Abundance
FASER
FASER2
BaBar
3 fb^{-1}
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}
Λ_m^{-1} [GeV^{-1}]
m$_0$ [MeV]
CHARM-II + LEP (Δ-Ins.)
EDM : Δ = 0.001
Relic Abundance
FASER
FASER2
BaBar
Λ_e^{-1} [GeV^{-1}]
m$_0$ [MeV]


MDM : Δ = 0.01
Relic Abundance
FASER
FASER2
CHARM-II + LEP (Δ-Ins.)
CHARM-II
BaBar
3 fb⁻¹
30 fb⁻¹
300 fb⁻¹
3000 fb⁻¹
Λ_m^{-1} [GeV^{-1}]
m_0 [MeV]
EDM : Δ = 0.01
Λ_e^{-1} [GeV^{-1}]



MDM : Δ = 0.05
Relic Abundance
FASER
FASER2
CHARM-II + LEP (Δ-Ins.)
BaBar
CHARM-II
ν-Cal
3 fb⁻¹
30 fb⁻¹
300 fb⁻¹
3000 fb⁻¹
Λ_m⁻¹ [GeV⁻¹]
m_0 [MeV]
EDM : Δ = 0.05
Λ_e⁻¹ [GeV⁻¹]


MDM : Δ = 0.001
Relic Abundance
FASER
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SHiP
EDM : Δ = 0.001
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Λ_m^{-1} [GeV^{-1}]
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